INVESTIGATING THE EFFECT OF BLADE CUTTING ANGLES OF A MANUAL HOE ON OPERATOR'S HEART RATE DURING WEEDING OPERATIONS

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ABSTRACT
The present findings focus on the assessment of manual hoe blade cutting angles on operator heart rate during weeding operation. Three hoe blades were developed with different blade cutting blade angles (65^o, 75^o, and 85^o) using AutoCAD software and analyzed by 3D modeling. Heart rate (bpm) was measured using a polar heart rate monitor and recorded at rest, during the entire period of work and recovery thereafter for a period of 5 mins. Soil bulk density and moisture content (db) were determined using a standard method from literature. Randomized Complete Block Design (RCBD) was employed to evaluate the effect of hoe blade cutting angle, soil moisture content, soil bulk density and the operator's height on the heart rate of the operator during weeding operations. Three levels of cutting angles (65^o, 75^o and 85^o), bulk density (1.2, 1.3 and 1.5 g/cm^3), moisture content (13, 15 and 18 %) and two different operator's heights (1.56 and 1.65 m) making a 3 x 3 x 3 x 2 factorial experiment design and analyzed using ANOVA and Tukey's Studentized Test mean comparison. Results obtained show that mean heart rate increases with an increase in soil moisture content, soil bulk density and operator's height respectively, but decreases with hoe blade cutting angle. The optimum heart rate of 84.24, 80.35, 72.01 and 74.61 bpm were obtained at 85^o blade cutting angle, 15% soil moisture, 1.2 kg/m^3 bulk density and 1.56m operator's height respectively. It was, however, recommended that a study on manual hoe be carried out to ascertain its effects on the weeding index, performance index and cost of operation.

KEYWORDS: Blade Angle, Bulk Density, Moisture Content, Heart Rate, Weeding

1 INTRODUCTION

A hoe (weeder) is an ancient and versatile agricultural and horticultural hand tool used to shape soil, remove weeds and harvest root crops (Mitchell, 2016). Weeding with a hoe includes agitating the surface of the soil or cutting foliage from roots and clearing soil of old roots and crop residues (Hussain *et al.*, 2018). Hoes for digging and moving soil are used to harvest root crops such as potatoes, yams and cassava. There are many types of hoes of varied appearances and purposes some have multiple functions while others have singular and specific functionality (Paltrinieri and Staff, 2014). There are two general types of hoe, Dutch hoes for shaping soils and scuffles hoes for weeding and aerating soil (Zwickle, 2011). In a country like Nigeria, most farmers use a manually operated hoe for the weeding of unwanted plants, planting of seed and harvesting of some crops Nkakini *et al*. (2010).

Agriculture offers the basic means of income for the majority of farm workers. The workers use various types of tools, equipment and machinery for their day-to-day activities in the agricultural fields (Awasthi *et al.,* 2019). Ergonomically designed equipment/tools enhance human operating efficiencies and comfort during its operation.

Ergonomic evaluation is a tool to evaluate the energy expenditure of work, their physiological cost and suitability of the method for farm workers and how long they can work continue without getting fatigued (Kumar *et al.,* 2013). The physiological cost of work includes the heart rate (HR), oxygen consumption rate (OCR) and energy expenditure rate (EER). The ease of performing an operation affects the output of the worker. The use of proper tools provides promising and encouraging results and hence it becomes of utmost necessity to consider the human factor in the design of farm tools to enhance the operating efficiencies, working comfort and thereby improve the productivity of workers. To evaluate the physiological workload using heart rate, the relationship between heart rate (HR) and oxygen consumption rate (OCR) must be determined for each subject (Tiwari *et al*. 2011). Both variables have to be measured in the laboratory at a number of sub-maximal loads. This process is called the calibration of subjects. With a linear relationship of the heart rate and oxygen consumption, the oxygen consumption (OCR) during the field trials can be predicted from the calibration charts (Aware *et al.,* 2018). The impact of physical work on the worker is an issue of concern as it leads to undue fatigue and strain on the worker. Malnutrition, poor body mass index, poor physical fitness and other biological responsibilities influence the worker in their attitude to work as ‘drudgery’ (Komatsu *et al.,* 2019). Heart rate is an important parameter to assess the drudgery of activity by estimating the physiological workload. Many scientists like (Hubert *et al.,* 2013, McCraty and Shaffer 2015, Peçanha *et al.,* 2017) have assessed the physiological workload of various activities using heart rate as an indicator.

Singh and Vinay (2013) found through discussion with women’s groups by using the Participatory Rural Appraisal (PRA) technique, that weeding was the most drudgery-prone activity with a scale value of 2.01 followed by harvesting, transplanting, cleaning and level of the field as perceived by the women. Weeding was identified as the maximum drudgery involved activity in the three zones of Northern Karnataka with a drudgery index of 51.11 percent (Kishtwaria and Rana , 2012).

During physical activity, the heart rate and oxygen consumption rate may be increased, depending upon the workload and the maximum values which could be attained in normal healthy individuals are about 190 beats/minute for heart rate and 2.01 litre/min. Maximal aerobic capacity (VO_{2max}) for oxygen consumption rate (Smolander *et al.,* 2008). However, at this extreme workload, a person can work only for few seconds. Generally, a workload that requires oxygen at a rate of about 35 percent of VO_2 maximum is considered as the acceptable workload and the values work out to be 0.70 litre/min. and 0.63 litre/min for male and female workers respectively (Gite, 1993). The corresponding heart rate values for this workload will be about 110 beats/min for men and 105 beats/min for women (Rai *et al.,* 2012).

Bisschoff *et al.* (2016) found that various body positions accounted for variation in the heart rate significantly. Heart rate differed significantly at the ball making, rolling and puffing action position from the normal sitting position, the angle of ankle and knee bend were significantly affecting heart rate. She also found that a relative increase in the angle of the armpit and knee bend would decrease heart rate of workers.

Coquart *et al.* (2014) obtained a significant correlation between perceived exertion and oxygen consumption at the maximal levels and linear relationship between perceived exertion and heart rate while carrying load.

Study conducted by Jena and Mohanty (2014) on cardiorespiratory efficiency in some agricultural workers that are germinating seedlings and threshing observed that average heart rate of 5 male subjects during rest was 75.2 ± 5.5 beats/min and it was increased during pedal threshing to 140.8 ± 4.3 beats/min. Similarly, when seedling operation was done the heart rate increased from 75.2 ± 5.5 (in rest) to 109.2 ± 3.0 beats/min.

Prasad *et al.* (2015) conducted a study on physiological reactions of eight female workers in Indian agricultural work with a view to standardizing their occupational workload of them. Maximum oxygen uptake (VO_2 max) was 1.892 litre per minute. Their daily energy intake was 11.65 MJ of which 85 percent was derived from carbohydrate. Average work pulse rate in many tasks was more than 130 beats/minute. Pounding alone or in pairs and digging of dry soil were the heaviest jobs, while harvesting, transplanting, uprooting and carrying load were moderately heavy. Whole day energy expenditure was 10.61 MJ.

In view of multiple and hard work done by farmers, it is necessary to make available farmers friendly manual hoe for labour saving, cost effective and simple farm work to save millions of farmers from drudgery, stress and ill health due to heart rate. Hence the aim of this study is to investigate the effect of blade cutting angles of a manual hoe on operator's heart rate during weeding operations.

2. MATERIALS AND METHODS

2.1 Criteria for modification of manually operated hoe

The existing manual hoe blade has single cutting edge. Single side of the blade is used in the removal of weeds from the ground. Normally, heavy loam soil consumes more energy and subjected more wear when compared with other soils (Chamen *et al.,* 2015). Based on the problem, it was identified that the manual hoe blade has effects on heart beat rate while removing weeds in the farm. This is because the existing design cannot contain the rate of heart beat which causes delay and negligence in weeding operation which affects the crop yield and the loss in crop yields and hence it is not convenient for the farmers to use it as stated by Bonny (2016).

During these activities, farmers adopt bending and squatting body posture due to which their physiological workload increases and also, they face many types of Musco-skeletal problems as a result of which the efficiency of work decreases to a great extent (Shahi *et al.,* 2018).

2.2 Design and development of the hoe

To begin the process of creating 3D models in AutoCAD the sketches from the concept section of the blades were used to develop an estimate of a scaled down set of dimensions for the different designs. These dimensions were applied to each design so that each blade have the same thickness, length, and circumference, thus making it possible to determine which connection would be the strongest and most reliable design as adopted by Jahun (2018).

Three different blades were developed (with different hoeing angles of 65°, 75°, and 85°) and developed with computer aided design (CAD) methods (**Error! Reference source not found.**1) and analyzed by 3D modeling. Geometrical parameters were used at initial stage as a basis for 3D modeling which are related to commercially available local hoe tool using 3D CAD software as reported by Jahun *et al.* (2019).

An AutoCAD software were used in the design of the manually operated hoes, the following blade angles were design and fabricated as 65^o, 75^o and 85^o. The Figure 1 is in 2D and 3D orthographic models of the designed manually operated hoes (Evans *et al*., 2012).

The weeding blades were made from 25 x 150 mm mild steel flats because it is strong enough to sustain the prevailing forces as well as to carry the load of the manual hoe. The blades were sharpened at the lower end so that it can penetrate into the soil at proper angle and desired depth during weeding. The blade was fixed at one end of the long round wooden handle of 26 mm in diameter and 500 mm in length at the other end.

a **b** **c**

Figure 1: Orthographic and 3D Model of Hoe Blade angles at (a) 65^o, (b) 75^o, (b) 85^o

2.3 Determination of soil bulk density prior to weeding

The cylindrical core sampler provides a fast method for obtaining representative samples of the surface profile prior to weeding, thus permitting large-scale experiments to be conducted. At random locations, undisturbed soil samples were collected using core samplers each from experimental plots digging depth of 20 cm. The samples were carefully trimmed at both ends of the cylindrical core sampler and weighed. The samples were oven dried at a temperature of 105^{o}C for 24 hours. It was reweighed after oven drying and the weight of the soil in grams divided by the volume of the core sampler in cubic centimetres gave the bulk density of the soil. This bulk density was calculated on a dry basis and was referred to as the initial bulk density (BDX).

2.4 Determination of soil moisture content

The core samplers were used for collecting soil samples and taken to the laboratory to determine the wet quantity before placing in electric oven at temperature 105^{o}C. Soil samples were taken out from oven and weighed to determine dry mass after 24 hours. The soil moisture content is defined as the ratio of the mass of water in a sample to the mass of solids in the sample, expressed as a percentage.

2.5 Methods of measuring the physiological parameters

Heart rate (beats/min) was measured with the help of polar heart rate monitor and recorded at rest, during the entire period of work and recovery thereafter for a period of 5 minutes. Energy expenditure was estimated from average heart rate during rest and during work by using Equation (1) for workers (Chauhan and Dayal, 2012; Foster, 2016).

$$EER\ (kJ/m) = 0.159\ \times AHR\ (bpm) - 8.72 \qquad (1)$$

where,

EER is energy expenditure rate (kJ/min), AHR is average heart rate (bpm)

Physiological workload was classified on the basis of working heart rate (Borah and Kalita, 2016). Total cardiac cost of work (TCCW) Equation (2) and physiological cost of work (PCW) Equation (6) were determined in this study by using average heart rate during rest and work, recovery heart rate and duration of work and recovery (Vyavahare and Kallurkar, 2012):

$$\mathrm{TCCW} = \mathrm{CCW} - \mathrm{CCR} \tag{2}$$

where,

TCCW = Total cardiac cost of work, beat/minute
CCW = Cardiac cost of work, beat/minute
CCR = Cardiac cost of recovery, beats

Hence,

$$\mathrm{CCW} = \mathrm{AHR} \times \text{Duration of work} \tag{3}$$

$$\mathrm{AHR} = \mathrm{AWHR} - \mathrm{ARTHR} \tag{4}$$

$$\mathrm{CCR} = (\mathrm{ARHR} - \mathrm{ARTHR}) \times \text{Duration of recovery} \tag{5}$$

where,

AWHR is average working heart rate, ARHR is average recovery heart rate, and ARTHR is average resting heart rate all in beat per minutes (bpm).

$$\mathrm{PCW} = \frac{\mathrm{TCCW}}{\text{Total Time of work}} \tag{6}$$

Cardiovascular Stress Index (CSI) was determined by using the formula

$$\mathrm{CSI} = \frac{100(\text{Heart rate during work} - \text{Heart rate during rest})}{\text{Heart rate during work} - \text{Heart rate at rest}} \tag{7}$$

2.6 Calibration of subjects

The oxygen consumption rate of the selected two subjects while hoeing on the field was measured using computerized ambulatory metabolic measurement system Metamax II. Prior to the test, their resting heart rate, oxygen rate consumption rate and blood pressure were measured.

2.7 Ergonomical evaluation of the manually operated hoe

The experiment was conducted with three manually operated design hoes in a Fadama field of vegetable crops in Bayara town of Bauchi LGA of Bauchi State. The mean maximum temperatures varied from 27.5 to 31.5 ^{o}C and 33.4 to 37.5 ^{o}C respectively during the period of evaluation. The trials with three different hoe angles were performed starting from three weeks to six weeks of planting. The field selected for field trials was planted with tomatoes and sweet pepper. The subjects were trained well for operating of the hoes. The trial was conducted between 8:00 am and 5:00 pm and the subjects were asked to report at the field at 7:30 am. Each trial started with taking five minutes' data for physiological responses of the subjects while resting on a stool under the shade. After resting period of half an hour, subjects operated the three hoes (Figure 2). Each trial was conducted for a period of 20 minutes. The heart rate was measured with the computerized ambulatory metabolic measurement system metamax II as shown in Figure 3. The same procedure was repeated for all the subjects. The values of heart rate for all the subjects was averaged to get the mean values for the three fabricated hoes.

Figure 2: Operators performing weeding with manual hoe

Figure 3: Measurement of heart rate immediately after operating the manual hoe

2.8 Experimental design and statistical analysis

A 3x3x3x2 factorial experiment using Randomized Complete Block design (RCBD) was used to evaluate the effect of heart rate on performance of different manually local hoes during weeding operation. The ranges of the factors were selected based on the review of literatures and preliminary laboratory investigations. The factors in the factorial design are three levels of each blade angles (65^o, 75^o and 85^o), three level of bulk density (1.5, 1.3 and 1.2 g/cm^3), three level of moisture content (13, 15 and 18 percent) and two different operator's height (1.65 and 1.56 m). Each test was performed in three replications making a total of 162 values (treatments) that were individually tested and measured.

Data obtained from the measured parameters were statistically analyzed for the Analysis of Variance (ANOVA) and further tests to compare the means of the measured parameters at each level of the weeding operation using Tukey's Studentized test with the aid of SAS 2010 software.

3 RESULTS AND DISCUSSION

3.1 Effects of blade angle on heart beat rate

Figure 4 presents the average of heart rate and clearly show that blade angles during weeding of crops had significant effect on heart rate. The averages amongst the heart rate were not the same. That is at least one of the average values was different. Tukey's comparison mean was conducted for the effects of blade angles on heart rate. Average means having same letters are not significantly different. From the average, it indicated that blade of 75^o and 85^o were not significantly different with mean values of 84.86 and 84.28 bpm. Similarly, blade angle of 65^o was significantly different with mean value of 86.04 bpm while weeding grasses in a vegetable farms. The American Heart Association states that the normal resting adult human heart rate is 60-100 bpm. From the field evaluation, it shows that the results are within the acceptable range only that hoe with blade angle of 65^o has the highest heart rate and blade cutting angle of 85^o gave the lowest heart rate. This is in agreement with the study conducted by Nag and Pradhan (1992).

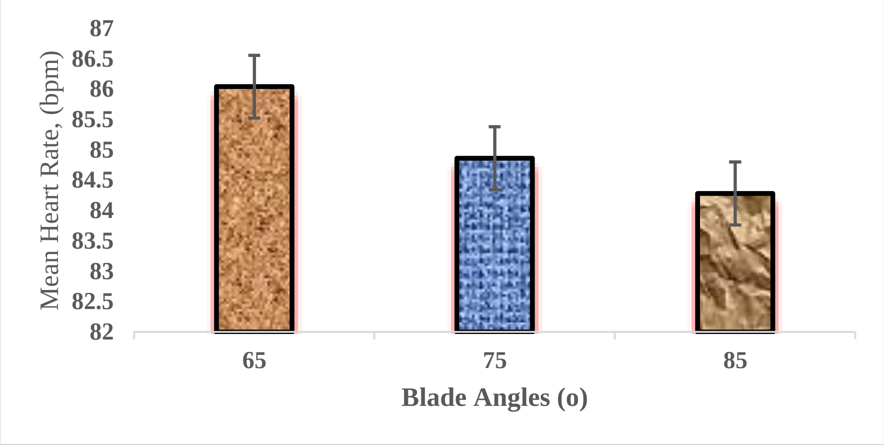

Figure 4: Effects of Blade Cutting Angle on Heart Rate

3.2 Effects of moisture content on heart rate

Figure 5 presents the average comparison using Tukey's mean separation method for the effects of moisture content on heart rate. The comparison mean explain that means with same letters are not significantly different. The average heart rate of 90.47, 80.35 and 100.28 bpm for moisture content of 13, 15 and 18 % (db) respectively were significantly different. The difference in the average heart rate clearly indicated that there was a significant difference among the moisture contents. Therefore, moisture contents were within the acceptable standard limit for operator's safe heart rate. They can be observed that moisture content of 15 per cent gave the minimum heart rate and moisture content at 18 per cent gave the maximum heart rate . It is recommended that soil moisture contents of 15 per cent is best for weeding grasses which is accommodating good heart rate for the operator. The results are in agreement with findings of Kankal *et al.* (2014).

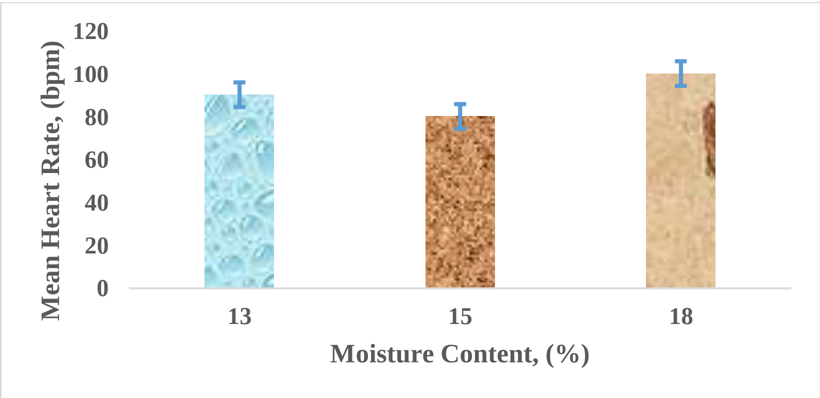

Figure 5: Effects of Soil Moisture Content on Heart Rate

3.3 Effects of Soil bulk density on heart rate

Figure 6 revealed that heart rate at bulk density 1.5 and 1.3 g/cm^3 were not significantly different with mean values of 85.33 and 84.81 bpm. Similarly, there were significant differences at bulk density of 1.2, 1.5 and 1.3 g/cm^3 with averages of 72.01, 85.33 and 84.81 bpm. It can be agreed that the average among the level of bulk density were not equal. At least one of the averages was different. The best weeding operation at bulk density was obtained by heart rate of 72.01 bpm even though they are within the range of safe operation. The result is in agreement with the reports by Singh *et al.* (2018) and Akintade and Adenigba (2018).

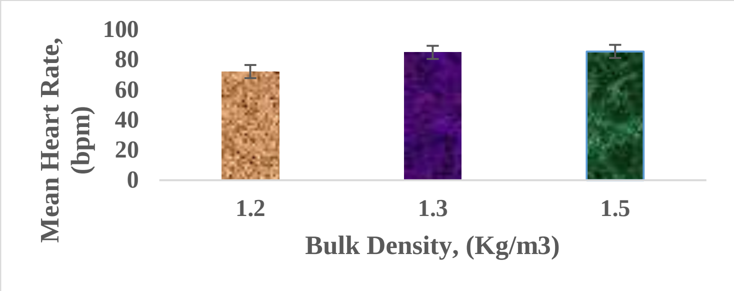

Figure 6: Effects of Soil Bulk Density on Heart Rate

3.4 Effects of height of operator on heart rate

Error! Reference source not found.7 present the mean effect operator height on heart rate. The results show that there was a significant difference between height of operators of 1.65 and 1.56 m on the heart rate. The average values recorded were 85.66 and 74.61 bpm respectively. From the results, better heart rate was obtained by 1.56 m operator height, meaning the heart rate required to weed grass sufficiently is obtained by the lower height of operator (Melander *et al.*, 2005).

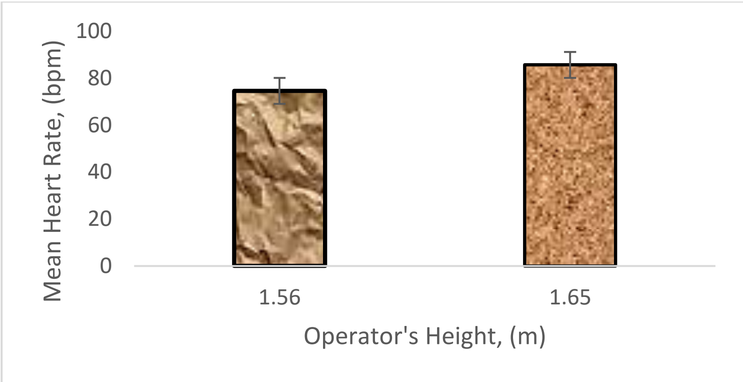

Figure 7: Effects of Height of operator on Heart Rate

3.5 Effect of blade cutting angle and height of the operator on heart rate

The average of the relationship between blade cutting angles and height of operator (H_1) on heart rate are presented in **Error! Reference source not found.**. It has shown that at least one of the average values of heart rate was significantly different. The mean heart rate for blades cutting angles amongst the height of operator (H_1) 1.56 m had a significant difference effect on heart rate, the mean values were 88.36, 79.72 and 92.89 bpm accordingly.

Blades cutting angles 65^o, 75^o and 85^o angles at height of operator (H_2) 1.65 m show significant difference on heart rate with average values of 96.02, 79.99 and 102.46 bpm respectively. The trend is showing that at 1.56 and 1.65 m heights of the operator there were significant effect on heart rate. Also, blade with 75^o angle with height of operator 1.65 m had shown significant effect on heart rate with minimum values of 79.99 m. The results are showing that at height of operator 1.56 m there were significant effect on heart rate. Also, blade with 75^o cutting angle with height of operator (H_1) 1.56 m had shown significant effect on heart rate with minimum values of 79.72 m.

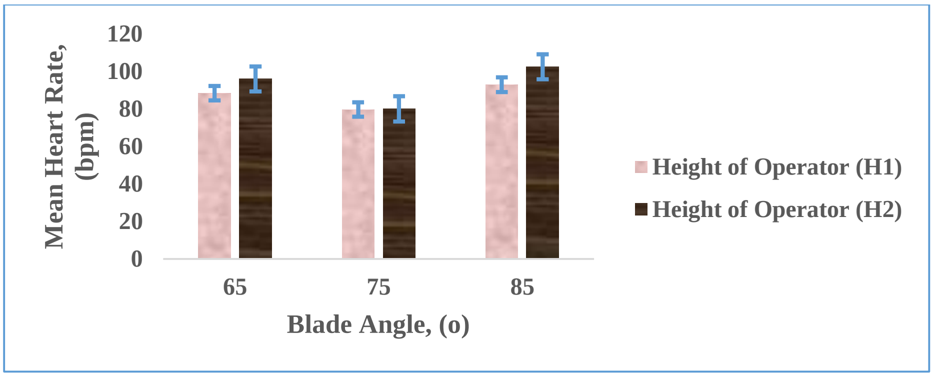

Figure 8: Effects of Blade Cutting Angles and Height of Operator on Heart Rate

3.6 Effects of Soil Bulk Density and Height of the Operator on Heart Rate

Error! Reference source not found. presents the average values of heart rate as it is affected by soil bulk density and height of operator. Bulk density showed high significant differences when interacting with height of operator of 1.56 and 1.65 m. Bulk density and height of operator (H_1) interactions show significant difference on heart rate at 1.2, 1.3 and 1.5 g/cm^3 with average values of 79.09, 81.41 and 89.01 bpm accordingly. Also, bulk density and height of operator (H_2) interactions had a significant difference on heart rate with average values of 82.39, 86.59 and 85.12 bpm respectively. The average heart rate had increased due to increase in bulk density as indicated that the maximum heart rate was obtained by bulk density with 1.5 g/cm^3 at height of operator (H_2) of 1.65 m. The minimum was obtained by the bulk density with 1.2 g/cm^3 for height of operator (H_2) of 1.65 m as in corroboration with McCausland *et al*. (2011).

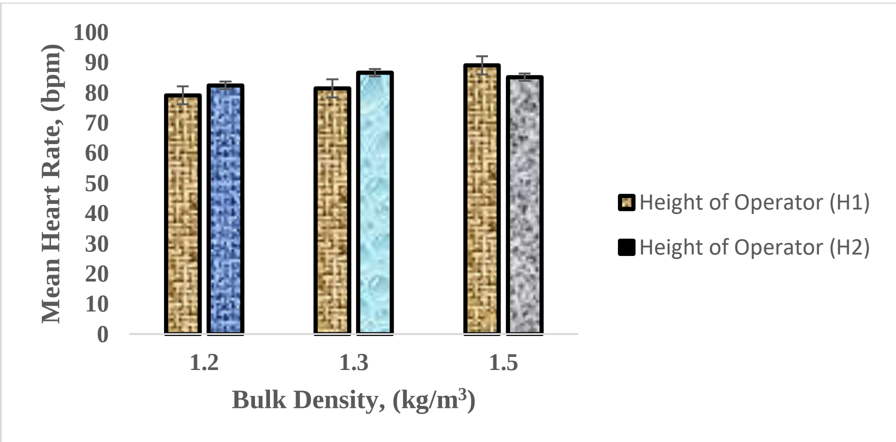

Figure 9: Effects of Soil Bulk Density and Height of Operator on Heart Rate

3.7 Effects of blade cutting angles, bulk density and height of operator on heart rate

Error! Reference source not found. presents the mean of heart rate as affected by blade cutting angles, soil bulk density and height of operator. Blades cutting angle of 65^o, 75^o and 85^o at soil bulk density of 1.2 g/cm^3 and operator height of 1.56 m recorded a significant difference on rate of heart rate with mean values of 66.93, 71.97 and 89.67 bpm respectively. Likewise, for blades cutting angle with 65^o, 75^o and 85^o at bulk density of 1.3 g/cm^3 and operator height of 1.56 m, heart rates were significantly different with averages as 73.64, 80.07 and 89.44 bpm, accordingly. Similarly, the interactions of bulk density of 1.5 g/cm^3, operator height of 1.56 m, blades cutting angle with 65° and 85° cutting angle indicates a non-significant difference with mean value of 90.89 and 104.10 bpm, while blades with 75° show a significant difference on heart rate having average of 84.36 bpm on weeding of grasses in a Fadama area. The combination of soil bulk density of 1.2 g/cm^3 and operator height of 1.65 m, blade with 65° and 85° showed non-significant difference with mean values of 82.73 and 99.32 bpm accordingly, while blade with 75° shows significant difference with average 77.60 bpm. Similarly, at soil bulk density 1.3 gm/cm^3, blade with 65° and 85° indicated non-significant difference with averages of 88.20 and 90.81 bpm respectively, but blade with 75° cutting angle shows significant difference on rate of heart rate with mean value of 82.89 bpm. Lastly, soil bulk density 1.5 gm/cm^3 and operator height 1.65 m, blades with 65° and 85° showed non-significant difference on rate of heart rate having averages 91.84 and 103.15 bpm respectively, while blade with 75° indicated that there was significant difference on heart rates with mean value 97.77 bpm. Based on the interactions, blade with 65° with operator height of 1.56 m gives the minimum heart rate of 66.93 bpm and blade of 85° and operator height of 1.56 m gave the highest heart rate. The finding is in agreement with McCausland *et al*. (2011).

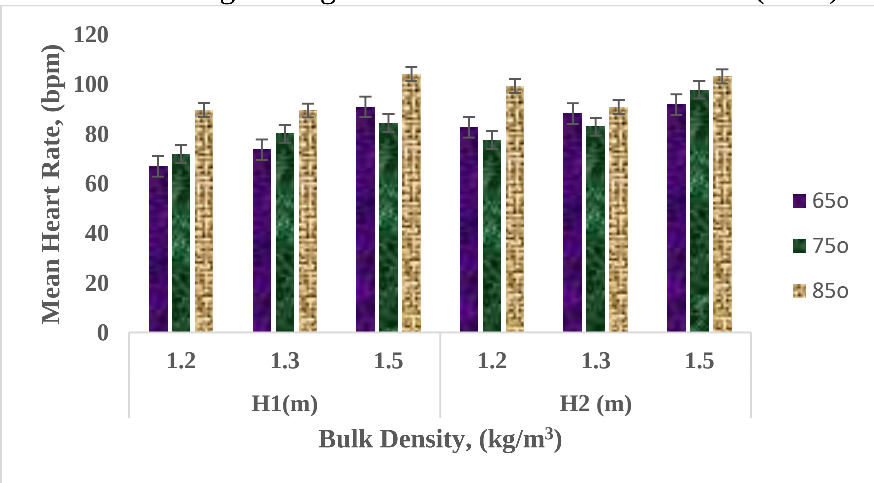

Figure 10: Effects of Blade cutting Angles, Bulk Density and Operator Height on Heart Rate

4 CONCLUSION

From the study carried out, the following conclusion were drawn.

- The heart rate increased as soil moisture content, soil bulk density and operator's height increased. While it decreases with blade cutting angle.
- The optimum values of heart rates obtained at a weeding conditions of 85° blade cutting angle, 15% soil moisture content, 1.2kg/m^3 bulk density and 1.56m operator's height are 84.28, 80.35, 72.01 and 74.61 bpm respectively.
- However, the interaction of the factors: blade cutting angle and operator's height (75° and 1.56m), soil bulk density and operator's height (1.2 kg/m^3 and 1.65 m) and blade cutting angle, bulk density and operator's height (75°, 1.2 kg/m^3 and 1.65 m) also gave a mean heart rates of 79.72, 79.09 and 71.97 bpm respectively.

Hence, it is recommended that blade with 75° cutting angle at 1.56m height of operator be used for weeding grasses which would give minimum heart rate amongst other blades cutting angle. Also, there is need for a further study on manual hoe to ascertain its effects on weeding index, performance index and cost of operation. This research also demonstrated that heart rate indices could be used as an effective means of determining the physiological strain of subjects working in Fadama areas in Bauchi State

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